Economic and Environmental Sustainability Assessment of Solar Photovoltaic Technology in Nigeria: Rural Electrification Perspective

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Abstract- The country, Nigeria, has large solar energy resource potentials yet to be tapped while her energy sector continues to go through insufficient electrical energy generation. This work identified some barriers and challenges hindering rapid development of solar PV applications in Nigeria and suggested new strategies of overcoming them in cases where solar PV is profitable and also considers necessary mitigation factors in some cases where it is not viable. The economic and environmental sustainability of solar PV technology was also assessed using Alare/Araromi village, as a case study. RETScreen modelling software was used to determine the economic feasibility and energy production capacity of Solar PV system using a total life cycle method of 25 years life span. The Net Present Value (NPV) is -\$1,585,220 and Benefit Cost Ratio (BC-R) is -0.78 at a tariff rate of \$0.766 /kWh while the greenhouse gases (GHG) reduced drastically. No profit-oriented company will ever invest in such project. However, it was observed, that the NPV becomes positive and the BC-R greater than unity, when a lower interest rate and a higher start-up grants were introduced. This work will provide the policy makers with different alternative ways of meeting the energy needs of rural areas.

Keywords: RETscreen, renewable energy, rural electrification, solar energy, viability

1. Introduction

Electricity is a major driving force for rapid economic growth, especially in a developing economy. As the population grows, there is incredible pressure on the countries' energy infrastructures in matching supply with demand [1, 2]. It is on record that about 573 million people in Africa, do not have access to electricity [2]. Lack of access to clean and sustainable energy supply especially in the rural areas is indeed a very serious challenge to most developing nations like Nigeria. One major problem militating against the economic and technological development of the country at all levels is lack of reliable electrical power supply [3].

Nigeria's electricity generation through grid, is grossly insufficient, thereby creating very wide energy supply-demand gap [3]. The current generation potential is about 12,522 MW with average output of 3000-4000 MW [2]. It is inefficient and absolutely unreliable. About 43% of the country's population have no access to grid electrification; even after the major reforms in the power sector [4]. Majority of the rural areas are yet to be electrified due to their remoteness and high cost of extending the grid which may not be economically feasible for profit-oriented power utility companies [4].

Renewable energy sources (RES) have been globally identified as a vital and promising option in reducing the detrimental effect of climate change [5, 6, 7, 8]. It is sustainable and environment-benign[8]. Some of the available RES in Nigeria, are solar, wind, biomass, small hydro and others. It is vital for socioeconomic and technological growth in Africa [9, 10, 11].

Solar energy is clean, cheap, inexhaustible and eco-friendly. The increasing interest in the use of Renewable Energy Sources (RES) especially solar PV as a means of electrification is as a result of decreasing cost of solar PV, climate change and the necessity to ensure energy security. Solar PV technologies applications will surely guarantee sustainable development [12]. Identifying potential site for the installation of PV plant is necessary to provide electricity which will enhance social and economic impact on the inhabitants [5, 13].

So many works have been carried out on the feasibility, risk management and viability assessment of solar PV technology for rural electrification [9, 13-27]. Adebanji et al [11] did a comprehensive comparative analysis of off-grid and grid-connected hybrid system using Abeokuta, Nigeria as a case study. Issues, future prospects and policy formulation framework were also discussed. The outcome of the research showed that the grid-connected HPS is better than the off-grid HPS in cost reduction and reliability.

Solar PV analysis for lighting purpose was carried out for the rural and semi-urban centres (in Gambia) to identify different project financing methods [13]. The methods include cash financing, credit financing through small-scale lending, provision of sales/service by retailers, revolving loan, and institutionally owned and maintained systems through leasing, government granted renewable energy concessions, and energy service companies. Kamalapur and Udaykumar [14] worked on feasibility of photovoltaic home systems in rural electrification of India and suggested that the implementation should be designed to meet the electricity requirement of individual communities and field-tested for local use. The work also suggested formation of cooperative societies to participate in managing the programme.

In a similar work, Mirzahosseni and Taheri [15] used RETScreen to perform a techno-economic analysis of solar plant installation in Iran. The authors analyzed three different scenarios considering the peculiarity of the electricity tariffs of Iran. The results showed a positive cash flow and a reduction in greenhouse gases emission in the third scenario. Rashwan et al [16] also did a comprehensive technical and environmental assessment on switching the electrical grid to renewable energy in a residential building in Saudi Arabia. The solar PV plant was evaluated considering the new electricity tariffs.

Ibrahim and Usman [17] worked on feasibility of Solar PV technology in Lafiagi, Nigeria for rural electrification using RETScreen software. The results showed that the project is economically viable. The authors compared the cost of paying (assuming the location is connected to the grid) to the case of a stand-alone solar PV. Owolabi et al [18] also performed a techno-economic viability of 6 MW Solar plant technologies in North eastern part of Nigeria-Yobe, Borno, Taraba, Bauchi and Adamawa. The research established the economic and environmental feasibility of solar PV plant in all the states in the region with Yobe having the highest solar energy generation of 11,385 MWhr.

Jolan et al. [19] carried out a feasibility analysis of 100 MW PV installations in Ethiopia using RETScreen software. The technical and cost analysis of the plant was carried out. Hence, the project is technical and environment-friendly. Even with the abundant high solar irradiations in the country, it is noted that solar PV applications in the country is at a preliminary level that is constraint to few small-scale and remote isolated applications. Most of the reviewed works so far, considered solar PV system in cases where it is profitable. What happens in cases where it is not viable? This work tends to identify some barriers and challenges hindering rapid development of solar PV applications in the rural areas of Nigeria and suggests strategies in overcoming them in cases where solar PV is profitable and also considers necessary mitigation factors in some cases where it is not viable.

1.1. Nigeria's Solar Energy Potentials

The country is abundantly enriched with high solar energy potentials considering its geographical location. It is well positioned within a good sunshine belt and fairly distributed solar radiation across almost all the regions. The coastal region has about 3.5 kWh/ m^2-day and the northern region experiences about 7.0 kWh/ m^2-day of average yearly solar radiation [20]. The solar radiation map of the country is as in Figure 1. Despite the abundant solar energy potentials in the country, the percentage solar technology applications in the energy generation mix is almost zero. Most of the few solar technology applications in the country are not viable. Moreover, utility companies are unwilling to extend the grid to the rural areas due to their remoteness, sparse/scattered population, low load demand factor and very difficult geographical locations. The low PV generation in the country can be attributed to some factors like lack of awareness on the path of the people, high capital cost, lack of technological know-how, weak governmental political will on PV electrification, inconsistent government policies e.t.c. Hence, the need to identify the constraints militating against large scale integration of RES into the generation mix [21].

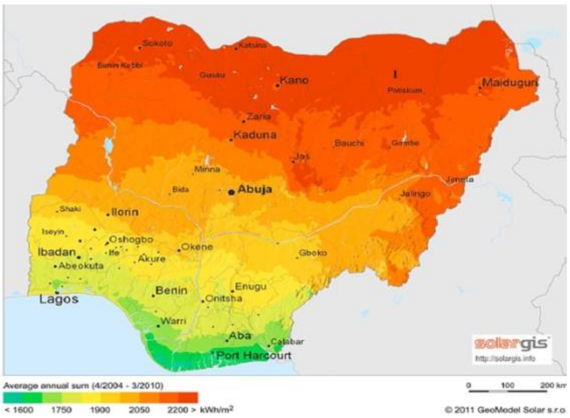

Fig. 1: Solar radiation map of Nigeria

The high cost of grid extension may not be economically attractive for any profit-oriented utility organization. But rural dwellers deserve efficient electric power supply for quality education, quality healthcare delivery, social/economic activities, and communication e.t.c. Even if the investment may not be economically viable, there is need for the government at all levels to introduce some incentives to attract private investors to invest in these communities.

1.2.1. Solar PV Rural Electrification

People living in the rural areas of the country suffer serious lack of electricity access due to scattered population, low load demand, far distance from the grid, topographic problems and low rate of solar PV technologies deployment. PV electrification has a very short project execution time compared to other sources of power generation. It is to be noted that the provision of efficient, sufficient and reliable power supply can be met by working towards diversification electricity generation in the country. Decentralised distribution generation systems are now being considered as the best option for the rural dwellers globally [22, 23].

Application of solar PV technologies will enhance better standard of living of the rural dwellers, more hours for studying, cooking, health care e.t.c. This will prevent migration of the people from the rural areas to the urban areas in search of non-existing job opportunities. The Federal Government of Nigeria (FGN) through its various agencies planned to massively pursued generation of electricity through solar PV. The target was to increase the generation of electricity through solar PV to 117 MW, 1343 MW and 6830 MW by the year 2015, 2020 and 2030 respectively [25, 26, 27]. The estimated target for the year, 2015 for instance, showed that the gap between the projection and the physical solar PV installations is very wide. The FGN seems to focus much of the attention towards grid and mini-grid electrification. The use of grid-connected PV projects has suffered vey slow physical implementation. Hence, for the rural areas, stand-alone PV system may be considered as the best solution for the electrification of these areas in meeting with various energy needs, health centre, pumping of water, telecommunications.

1.2.2. Drivers and Barriers of Solar Energy Development

The high solar radiation available in almost every part of the country is a major driver for solar technologies applications in Nigeria. This serves as an encouragement to would-be investors in solar technology. The increasing population along with corresponding energy demand will also provide a ready-made market for electric power production. This will create more employment opportunities for the youths. Hence, the urgent drive for alternative ways of meeting this, through RES like solar energy. The need to mitigate greenhouse effects and its attendant environmental effects also necessitated the gradual shifting from fossil fuel power generation to environment-benign energy generation sources.

The Electric Power Reform Act (2005) that allows individual to operate power plant that generate less than 1000 kW in a particular site favours the generation of electricity through RES. The reforms serve as an encouragement for more investments in RES [27]. Some of the major drivers of solar technology applications in the country are energy security, increasing need for local added content and non-conflicting energy use sources [27].

Despite the high solar radiations, different level of motivations, inherent advantages and benefits of solar technologies available in the country, solar energy applications in Nigeria are still faced with so many challenges. In order to ensure rapid growth of solar PV technologies utilization in both urban and rural areas, there is need to identify some of the major challenges confronting its implementation. Some of these barriers are too high initial investment costs, the stochastic solar radiation, low level of awareness of PV innovations, unreliable grid system, rising generation/maintenance cost, inconsistent government policies, poor quality control of solar products, land use competition/rivalry e.t.c. [27].

1.2.3. Strategies of overcoming the barriers

Governments at all levels (FGN, state and local) need to show strong political will in overcoming some of the identified challenges/barriers (as discussed in section 1.2.2) by formulating effective favourable policies in ensuring rapid solar energy applications and development in Nigeria [27]. Some of the suggested steps and strategies are as discussed in the following sub sections.

(a) Formulation of Favourable Government Policy

Government needs to formulate policies that will ensure sustainability of the solar energy development in the country. In order to attract investors, there is need to introduce some incentives that will attract new investors. The current tariff-structure is not cost-reflective for profitable investments, for there is need to maintain stability in pricing to attract new investors.

(b) Continuous Awareness Campaigns

There is need to embark in aggressive campaigns on the various advantages and benefits from solar energy applications. The public needs to be enlighten on the detrimental effects of fossil fuels and greenhouse effects. This will surely improve the desire of the people all over the country. Public awareness will also help in solving the problem of insecurity of solar energy infrastructures.

(c) Reduction of Investment Cost

The initial capital cost of investment in solar plant system is one of the major barriers to its development. Commercial banks should be encouraged to give loans to investors at lesser interest rates that is favourable to investors. Soft loans with low interest rates can also be provided.

(d) Reduction of Political, Economic and Regulatory Risks

Major stakeholders in the power sector need to possess the needed strong political will to establish policies and reforms to effectively manage political and economic structures for sustainable growth in solar technologies. The reforms should be sustainable to enhance reduction in political and regulatory risks. This will enable transparency in reducing the major barriers of solar energy technology.

(e) Effective Quality Control of Solar Infrastructures

Poor quality of some solar energy projects is one of the major impediments to solar energy projects. The FGN needs to be firm in establishing effective quality control of solar energy equipment through some of its agencies like Standard Organisation of Nigeria (SON), ECN e.t.c. The laws should be established and enforced to ensure quality control of these equipment to encourage local production of the equipment.

(f) Land Use Competition Reforms

Investments in large-scale solar projects often create a trade-off scenario in competing with the usage of the land for agricultural purposes. Hence, the need for public awareness about the benefits of solar projects for rural electrification. There is need for governments to compensate the land owners for the usage of their farmlands [27]

2. Methodology

2.1. Research Approach

The study involved the use of both quantitative and qualitative analysis. The villagers were interviewed on the energy needs, project feasibility and the willingness to pay for electricity consumed. All relevant data were gathered and analysed to determine the technical, economic, social and environmental viability of the project. A 600 kW stand-alone photovoltaic system was modelled using RETScreen for the study area. The evaluation was done using economic parameters like Net Present Value (NPV), simple payback to measure its viability, equity payback and net Internal Rate of Return, (IRR). The results obtained were analysed and discussed.

2.2. The RETScreen model

RETScreen Software comprises of a set of workbooks that is based on Microsoft Excel-models. Each workbook models' individual type of power system/application. It enumerates the various types of financial parameter indices that enhance comparison among other project with keen consideration of the project economic feasibility. The first version of the software was made available to the public in May, 1988 by the Canadian government. This laudable feat was achieved with technical/expertise supports from multi-organizations like NASA, DTIE, EEF, GEF, UNEP, PCF, e.t.c.

RETScreen 4.0 software is a clean energy analysis tool that can easily be used in making quick decisions in order to identify and optimize technical and economic viability of potential clean energy project [19]. It allows investors to assess and be confident of actual effects of their projects and seek helps in finding alternative energy saving opportunities. RETScreen analysis process is as shown in Figure 2.

Process analysis

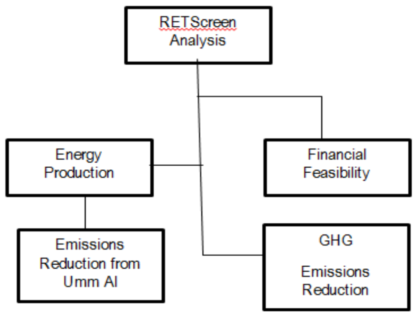

Fig. 2 Research steps Flow diagram [19]

2.3. Study Area and its Climatic Data

The study location selected is Alare / Araromi village-Efon Alaaye Ekiti, Nigeria. The village is located on the $7^0$29'.062" North and $5^0$13'.627" East (Long. 5.3908 and Lat. 7.5006). It has few small scale business establishments and agricultural extension units. The location on Google map is as in Figure 3. The climatic data is shown in Table 1. The monthly solar irradiation is as in Figure 4.

Fig. 3 Case Study on the Map (Google Map)

Table 1: Climatic Data of the Study area

Month	Air Temperature (˚C)	Relative humidity (%)	Precipitation (mm)	Daily radiation horizontal (kWh/m2d)	Atmospheric pressure (kPa)	Wind speed (m/s)	Earth temperature (˚C)	Heating degree-days 18˚C (˚C.d)	Cooling degree-days 10˚C (˚C.d)
January	24.1	62.9	9.92	5.57	97.0	2.1	23.9	0	437
February	25.8	64.5	19.04	5.74	96.9	2.3	26.3	0	442
March	26.4	73.4	57.97	5.66	96.8	2.6	27.1	0	508
April	26.1	81.2	119.70	5.34	96.8	2.8	26.6	0	483
May	25.4	85.3	163.37	5.02	97.0	2.5	25.7	0	477
June	24.5	87.7	211.20	4.51	97.1	2.5	24.7	0	435
July	23.5	88.5	234.05	3.89	97.2	2.9	23.8	0	419
August	23.4	88.5	217.31	3.73	97.2	3.0	23.6	0	415
September	23.9	88.5	260.10	4.06	97.1	2.3	24.1	0	417
October	24.4	87.0	169.57	4.62	97.0	1.8	24.5	0	446
November	24.5	78.8	27.60	5.18	97.0	1.7	24.3	0	435
December	23.7	68.4	12.40	5.37	97.0	1.9	23.3	0	425
Annual	24.6	79.6	1,502.23	4.89	97.0	2.4	24.8	0	5,340

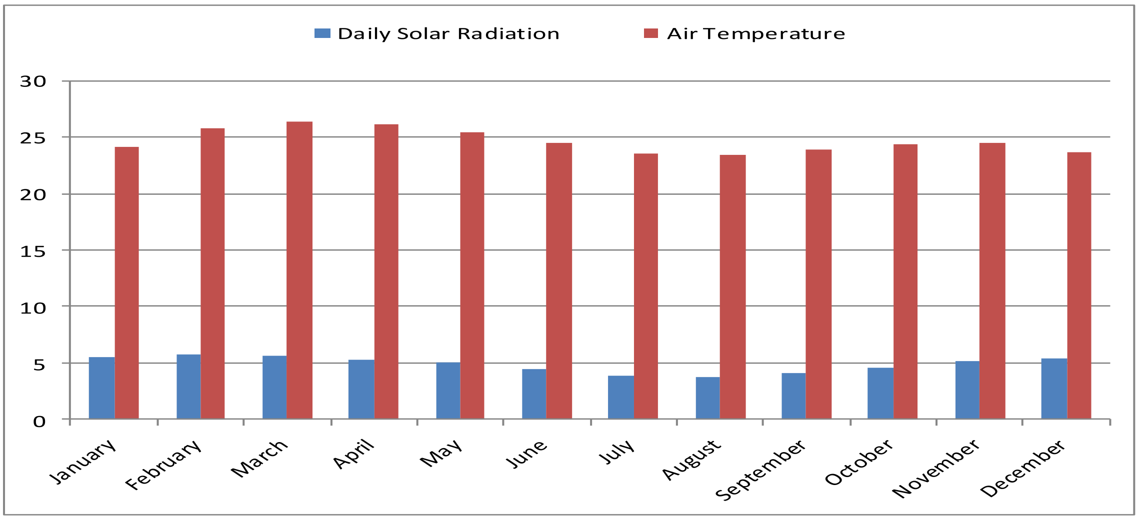

Fig. 4. Monthly Solar irradiation of the study area

2.4. Energy Usage Assessment

The load estimation used for the location is as in Table 2. The total daily electricity demand is 507.31 kWh while the yearly electricity need is 185.16 MWh. The highest load for the configuration is 50.912 kW and the work assumes a peak load of 41.2 kW. The inverter capacity used is 150 kW (Efficiency-90% and miscellaneous loss-5%).

The work also used a 150 kV battery (Efficiency-90%, maximum DOD-80%, charge controller efficiency-90%, and 5 days autonomy). The solar panels tracking mode is assumed to be fixed at 59^0 slope of and azimuth of 0.00. A mono-silicon PV panel (model: mono-Si–CSUN-250-60M) with a relatively high efficiency of 18 % used.

2.5. Design and Sizing of the Solar PV System

(1) Solar PV Generator Sizing: The peak power of the solar PV Array is as in equation (1) [22].

$$P_{PV} = \frac{E_d}{PSH \times \eta_{CR} \times \eta_{inv}}$$

where E_d=daily energy consumption, PSH = Peak

Sunshine Hours, η_{CR} =charger regulator efficiency and η_{inv}= inverter efficiency.

Table 2. *Estimated load of Alare/Araromi*

Category	Final use	Load Type	Rated Power (W)	Quantity (No)	Total Wattage (kW)	Operating (Hr/day)	Usage (hr/day)	Load (kWh/day)
Residential	Households	Lighting	5	81	0.405	16.00-6.00	14	5.a67
		Radio	5	79	0.395	17.00-2.00 05.00-7.00	7	2.765
		Telephone	3	194	0.582	17.00-9.00	2	1.164
		Fan	50	40	2.000	12.00-5.00	17	34
		Refrigerator	700	3	2.100	00.00-4.00	24	50.4
		Television	230	11	2.530	16.00-3.00	7	17.71
Commercial	Community	Water well pump	1000	1	1.000	16.00-9.00	3	3
		Streetlight	100	10	1.000	18.00-6.00	12	12
		School	2700	1	2.700	08.00-6.00	8	21.6
		Health centre	5400	1	5.400	06.00-2.00 19.00-6.00	17	91.8
		Worship centre	1800	1	1.800	05.00-7.00 17.00-9.00	4	7.2
Industrial	Factory	Milling machine	1500	4	6.000	07.00-7.00	10	60
		Factory machine	25000	1	25.000	09.00-7.00	8	200
Estimated Total					50.912			507.309
Approximated load								600

(2) Battery storage: The storage capacity is calculated using equation (2) [22]

$$Battery\ capacity = \frac{N_c \times E_L}{DOD \times \eta_{BAh} \times V_b} \qquad (2)$$

where N_C =autonomy days, E_L= required daily energy from the battery, DOD = maximum Depth of Discharge,

η_{BAh}= ampere hours efficiency and V_b= selected nominal DC voltage of the battery bank

(3) Sizing the Charge Controller

The size of the controller = peak rated current from the array × safety factor (3)

3. Results and Discussion

3.1. Electricity Production for the Study Area

The capacity of the power plant depicts the ratio of the actual energy production to the optimal capacity on the nameplate. The capacity of the PV power plant is estimated to be 17.44 %. The total yearly energy solar plant over the area gives a specific yield of 1.78 MWh/m^2. The electricity production reached its peak between the month of January and December with production of 71.94 MWh and 71.73 MWh respectively. The reduction in the electricity production between May and September is likely to be caused by the very low (summer) solar irradiations that reduced the solar cells efficiency. The monthly electricity generation is as in Figure 5.

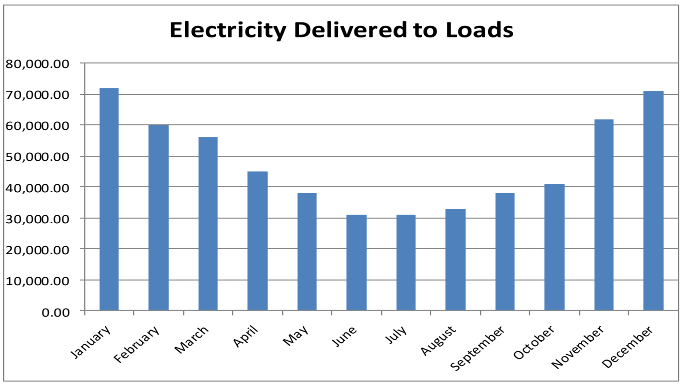

Fig. 5. Monthly electricity production

3.2. Economic and Emission Analysis (Base Case)

The financial viability result of the solar PV system (base case) in the village showed that the project is not economically viable. The Net Present Value (NPV) is -$1,585,220 and Benefit Cost Ratio (BC-R) is -0.78 at a tariff rate of $0.766 /kWh. The annual life cycle savings is -161,385/year, the IRR on equity is 5.5% while the IRR on assets is 3.3%. The simple payback time is larger than the project life time. All the viability parameters indicate that the project is not viable economically. Investors may not be willing to venture into such project unless significant policy formulation favourable to attract investors is done. This can be in form of tax holidays, reduction in initial capital cost e.t.c.

The cumulative cash-flow (CCF), as in Figure 6, gives a better picture of the viability of the project under the base case consideration. The outcome showed that the installation of the solar PV system in the location is not a financially viable option considering the current market conditions. Table 3 depicts the simple payback period for the village in the study area, demonstrating that the periods are shortest for Alare/Araromi with 11.3 years payback. From an economic standpoint, the payback period values for Alare / Araromi village is shorter than the projects suggested 25-year lifespan. The cumulative cost flow graph for the base case is depicted in Figure 6. The possible net emission reduction for the off-grid PV system for the selected location (Alare/Araromi) was determined using RETScreen emission analysis tool. The gross Annual GHG emission reduction is as in Figure 7.

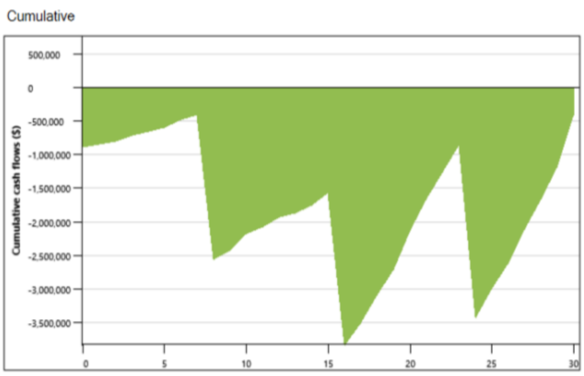

Fig. 6. CCF graph (base case)

Table 3. *Financial viability of Alare / Araromi PV system (base case)*

Financial visibility	
Pre-tax IRR- Equity	Negative
Pre –tax MIRR- equity	5.5%
Pre-tax IRR assets	Negative
Pre –tax MIRR- assets	3.3 yr
Simple playback	.3
Net present value (NPV)	-1,585,220
Annual life cycle savings	-161,385
Benefit -Cost (B-C) ratio	-0.78
Debt service coverage	-8.4
GHG reduction cost	357
ENERGY PRODUCTION COST	0.766

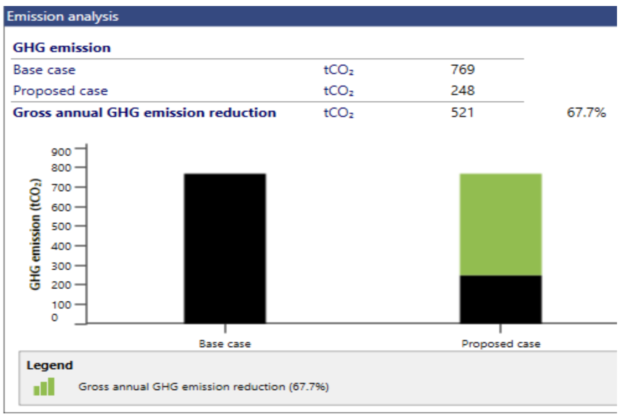

Fig. 7. Gross Annual GHG emission reduction

3.3. Economic and Emission Analysis (Adjusted Scenario)

As discussed in the base case scenario, the project is not economically viable. However, there is need for the government to make some financial adjustments in the execution of such projects to attract would-be investors.

The results of the adjusted financial scenario analysis showed that the project's viability increases with lower debt interest rates, lower inflation rates, and introduction of start-up grant to cover certain percentage of the total initial cost. The viability of the project improves when certain percentage of the project's costs was increased. Under this scenario, the results showed a positive NPV USD $8,295,699 and ALCS of USD $844,554/yr. Some other financial parameters for the adjusted scenario include: IRR on equity (13.6 percent); IRR on asset (12.8 percent); simple payback time is instant; and equity payback time is immediate (8.1 years). Figure 8 depicts the adjusted scenario's CCF graph.

Table 4. *Financial viability for the proposed case study*

Emission analysis	
Based case	769
Proposed case	248
Gross annual GHG Reduction	521 (67.7%)

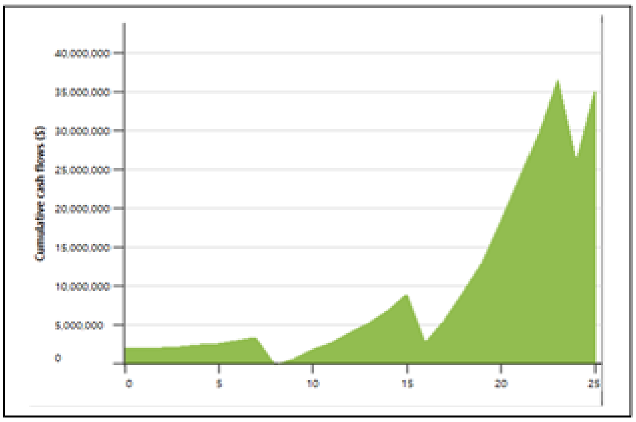

Figure 8: CCF graph (adjusted scenario)

5. Conclusion

This work identified some barriers and challenges hindering rapid development of solar PV applications in Nigeria and suggested new strategies of overcoming them in cases where solar PV is profitable and also considers necessary mitigation factors in some cases where it is not viable. Some of the major barriers to the electrification of rural areas through solar energy are high investment cost, lack of technological know-how and low level of awareness among the populace. Government at all levels should be actively involved in rural electrification projects through the use of solar technology. This will reduce the problem of insufficient generation and heavy dependence on the limited available electricity from the grid. Solar PV rural electrification brings about poverty reduction, climate protection, economic and viable production use.

To buttress the point, this work also examined the economic and environmental sustainability of solar PV technology using Alare/Araromi village, as a case study. The RETScreen modelling software was used to determine the economic feasibility and energy production capacity of Solar PV system using a total life cycle method of 25 years life span. The results of the analysis showed that the project is not economically viable based on the prevailing market variables. No profit-oriented company will ever invest in such project. People in the rural areas may find it very difficult to pay for the installation cost of the PV systems considering their socio-economic class.

Solar energy is a very reliable way of generating electricity for rural areas since it requires little maintenance and environment benign. The government and major stakeholders should formulate policies and appropriate legal frameworks to give the potential investors some level of confidence and assurance of a fair level playing ground and ability to recover their initial investments within not too long a time.

Author Contributions

B. Adebanji: Conceptualization, Methodology, Software, Writing – original draft, Writing – review & editing. **A. Osalade:** Writing – review & editing, **S. A. Adeleye:** Methodology, Software, Writing – review & editing, **T. Fasina:** Writing – review & editing, **A. Abe:** Writing – review & editing, **C. Okafor:** Writing – review & editing,

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